Antenna Measurements Using the Mirror Method with Gating in a Time Domain

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Abstract. *This paper provides a principal overview of the time domain measurement instrumentation and information about the implementation of the time domain option in the Agilent PNA microwave network analyzer E8364A. The paper also presents practical experiences with antenna measurements realized by sweep mode of a vector network analyzer with data processing in a time domain. The new single antenna methods of gain and antenna radiation patterns measurements are presented. These mirror methods with gating in a time domain are based on the reflection coefficient measurements realized in the frequency domain with time domain data processing. These methods seem to be promising for measurements of gain and radiation patterns of ultra-wideband linearly polarized antennas. The paper compares the results of the new methods with the results of standard measurements.*

Keywords

Antenna measurement, mirror method, time domain, radiation pattern, gain.

1. Introduction

The antennas are characterized by a set of parameters, such as impedance, radiation patterns, gain and polarization. These parameters are usually measured in the frequency domain, using instrumentation (scalar or vector analyzers) with good frequency discriminability. Similar results and more benefits can be obtained by using time domain measurement systems. The first advantage of time domain measurement is that it is considerably less time-consuming, because a whole frequency spectrum is derived from just one measurement. The second advantage is the fact that these systems contain a time-gating instrumentation, which allows signals to be isolated and separated in time. The mirror method of antenna gain measurement in the frequency domain is well known, but the problems associated with this method result in its low practical value in precision gain measurements [4]. The application of the time domain measurement, or data processing (i.e. gating) in the time domain, into the mirror method increases the accuracy of this method.

2. Time Domain Measurement Instrumentation

The instrumentation systems used for time-gated measurements can generally be divided into 4 groups: chirped waveform (FMCW) systems, step chirp frequency continuous wave systems, hardware gated continuous wave systems, and pulsed intermediate frequency systems [1]. All experiments mentioned in this article were realized on the Agilent PNA microwave network analyzer E8364A, because presently it is the only instrumentation available for time domain measurement in our department. The Agilent PNA microwave network analyzer with the time domain option installed is a step chirp frequency continuous wave system. The sequence for time domain measurement is shown in Fig. 1. The analyzer makes swept frequency response measurements. With the frequency response data the analyzer calculates the step, impulse, or band pass response of the device being tested, depending on the transform (inverse Fourier transform) selected. If the responses are in the time domain, the analyzer can filter out undesired responses, using gating function. Finally the analyzer transforms (Fourier transform) the desired responses back to frequency domain. Detailed information is available in [2].

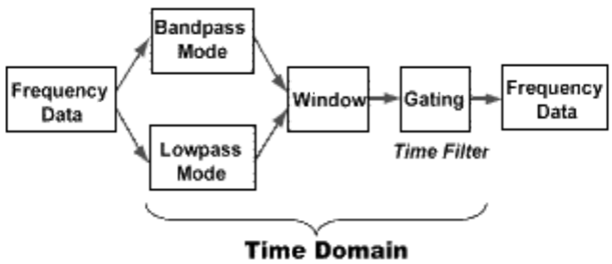

Fig. 1. The sequence for time domain measurements of Agilent PNA microwave analyzer E8364A.

The range resolution of the time domain measurement depends on the bandwidth of measurement as well as on weighting of the frequency domain data. It can be roughly calculated [1]

$$R \cong \frac{c}{2 \cdot BW}, \tag{1}$$

with c being the propagation velocity and BW the bandwidth of the measurement. The weighting of the frequency domain data is implemented by Window selection in Fig. 1, which optimizes the time domain response by providing smooth transitions to zero at the ends of the sample period. At the same time, window selection affects the measurement range (inverse to the range resolution) and the dynamic range, which is an important parameter of the measurements realized in the time domain.

3. Antenna Reflection Coefficient Measurement

A lot of useful information about the antenna's interior can be determined from a reflection coefficient measurement performed in time domain. Fig. 2 shows an example of the magnitude of the reflection coefficient measurement of a double-ridged horn antenna DRH20 [3] in the time domain. For this experiment, the vector analyzer E8364A with the time domain option was used. The measurement was carried out on 1801 frequencies in a frequency band from 2 to 19 GHz. Calibration of the vector analyzer was performed on the plane of the coaxial connector of the antenna to correct possible reflections in the coaxial cable and to determine a time delay of the reflected signal (0 ns on the time scale and also 0 mm on the distance scale correspond to the plane of calibration) in a simple way.

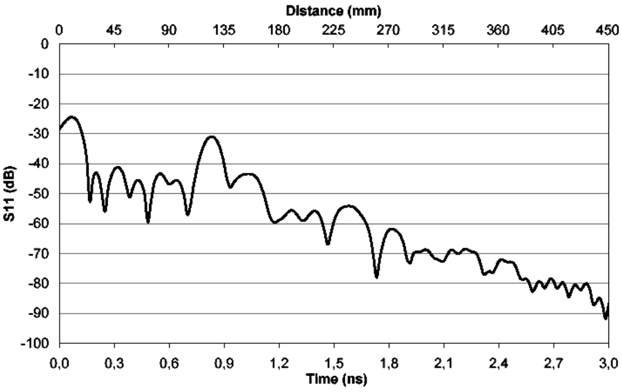

Fig. 2. Magnitude of a reflection coefficient S11 of the antenna DRH20 measured in the time domain.

The maximum peak of the reflected signal is at the distance of 10 mm from the plane of calibration at the point of the coaxial to the waveguide adapter. The second maximum peak is at the distance of 125 mm, which is in agreement with the sum of the length of major part of the antenna DRH20 (its total length is 122 mm) and the length of the coaxial connector (about 10 mm). Reflections between these two maximums are lower than -40 dB, which illustrates good antenna performance.

4. Mirror Method of Gain and Antenna Radiation Patterns Measurement

These methods emerge from a frequency domain mirror method of gain measurement [4]- see Fig. 3a. The antenna under test (AUT) is placed at a distance R from the plane reflector and directed to the center of the plane reflector, which reflects the transmitted energy back to the AUT. The gain of the antenna is determined from transmitted power P_T, the received power P_R, the distance R and the frequency. There are many problems involved when using this method for precision gain measurements (e.g. finite isolation of P_T and P_R, diffraction on the edges of the reflecting plane, undesirable reflections from neighboring objects, multiple reflections, losses of the reflector, reflector deviation). Gating in the time domain measurement eliminates most of these problems. The experiment set-up of the mirror method of gain measurement with gating in the time domain is depicted in Fig. 3b [5]. If the AUT is placed on a turntable, this system can be applied to antenna radiation patterns measurement.

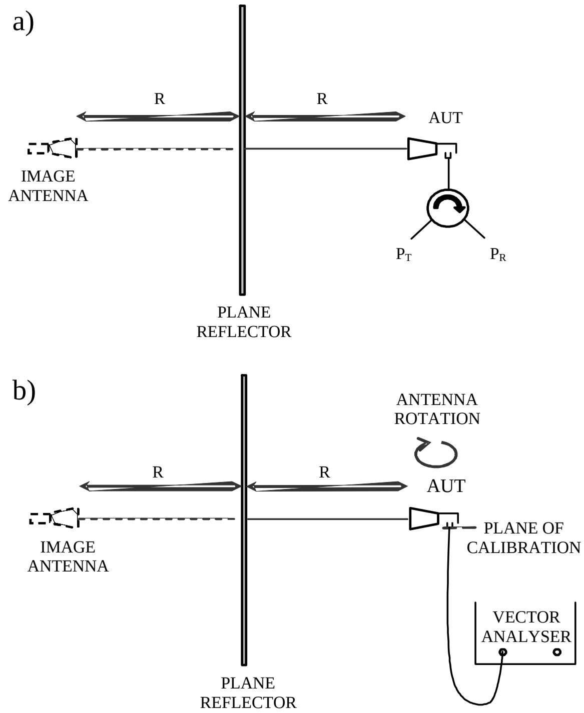

Fig. 3. a) Test configuration for the mirror method of gain determination [4]. b) Test configuration for the mirror method of gain and radiation patterns determination with gating in the time domain.

4.1 Mirror Method of Antenna Radiation Patterns Measurement with Gating in the Time Domain

The presented new mirror method of the measurement of radiation patterns with gating in the time domain is based on the usage of a flat reflector and a gating function of a vector analyzer (with time domain option), which is set to the antenna reflection coefficient measurement. For every angle of measurement the analyzer filters out all responses except the desired signal, which is returned from the flat reflector to the AUT. In our experiment, a double-ridged waveguide horn DRH20, see Fig. 4, was placed on a turntable at a distance of 5.35 m from the plane reflector with the dimension 2 x 2 m.

Fig. 4. Double-ridged waveguide horn antenna DRH20.

The measurement of the AUT radiation patterns started with the antenna main lobe oriented backward to the reflector (angle 0°). The vector analyzer was set to the antenna reflection coefficient S11 measurement in a frequency band from 2 to 19 GHz. A calibration of the vector analyzer was performed at the plane of the coaxial connector of the AUT to correct possible reflections in the coaxial cable and to simply determine the time delay of the signal reflected from the plane reflector. For every measurement angle, the analyzer filtered out all responses except the desired signal which was returned from the flat reflector to the AUT. The time domain data responses of the double-ridged waveguide horn DRH20 for measurement without gating are represented in Fig. 5, and for measurement with gating from 35.5 to 37.5 ns in Fig. 6. The time domain responses in these figures were recorded with the main lobe of the antenna DRH20 directed perpendicular to the plane reflector surface. The time domain data response of the double-ridged waveguide horn without gating contains a number of peaks caused by the reflections inside the antenna or reflections from surrounding objects. The significant reflection peak at 36.4737 ns corresponds to the reflection from the plane reflector. The corresponding distance 5.467 m includes the antenna aperture to the reflector surface distance and the antenna connector to the antenna aperture distance. The gating interval (2 ns) was chosen approximately 2 times wider than the optimal set-up, which would suppress signals diffracted on the edges of plane reflector. This gating set-up was chosen because the position of the AUT phase center was not known and because errors caused by changes of the distance between AUT phase center and reflector during antenna rotation could be eliminated.

Fig. 7 shows the magnitude of the reflection coefficient S11 of the antenna DRH20 obtained from the mirror method with gating in the time domain. The determination of the antenna radiation pattern from reflecting coefficient S11 is shown in the empirical equation:

$$PL_{dB} \approx 0.5 \cdot S11_{dB} \tag{2}$$

with PL_{dB} being the radiation pattern level of the AUT in dB, and $S11_{dB}$ being the gated reflection coefficient of the AUT in dB. The constant *0.5* represents the fact that the change of the signal reflected from the plane reflector is twice the size of the change of transmitted signal (change of the gain of the AUT and also of the image antenna).

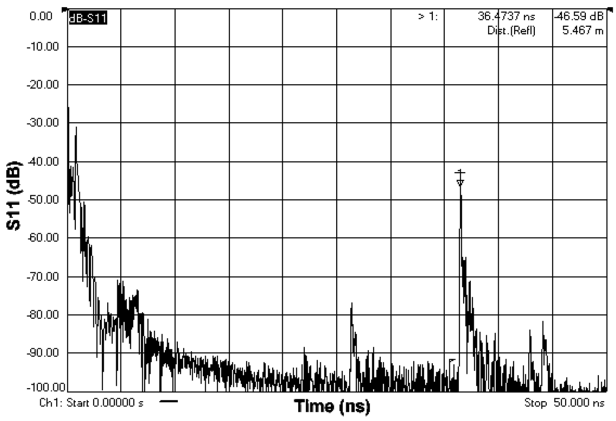

Fig. 5. The time domain data responses of double-ridged waveguide horn DRH20 without gating.

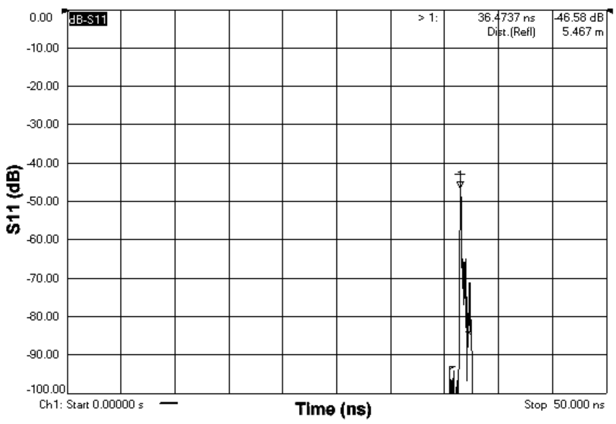

Fig. 6. The time domain data responses of double-ridged waveguide horn DRH20 with gating from 35.5 to 37.5 ns.

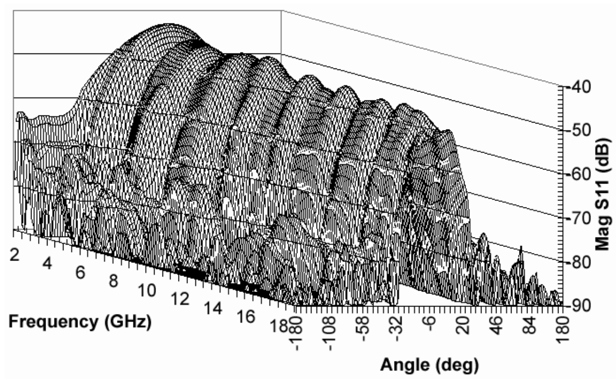

Fig. 7. Magnitude of the reflection coefficient S11 of the antenna DRH20, measured using the mirror method with gating in time domain.

Fig. 8, 9 and 10 show the comparisons of the double-ridged waveguide horn (DRH20) radiation patterns measured by a far-field range (full lines) and the mirror method with gating in the time domain (discrete points) for the above mentioned arrangement. The results show a good agreement for the first 15 - 20 dB of the radiation patterns' dynamic range. This limit is mostly caused by the principle of this method (constant 0.5 in Equation 2). The antenna DRH20 could be measured at a minimum distance of 1.1 m from the plane reflector, which would improve the radiation patterns' dynamic range. Another factor limiting measurable dynamic range is a maximum available dynamic range of used instrumentation for the time domain measurement [2].

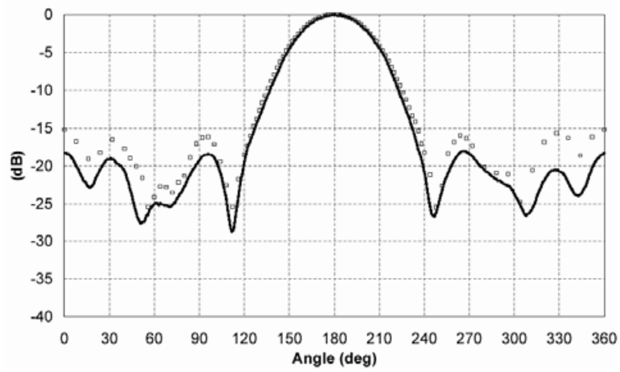

Fig. 8. The radiation patterns of the antenna DRH20 at 4 GHz.

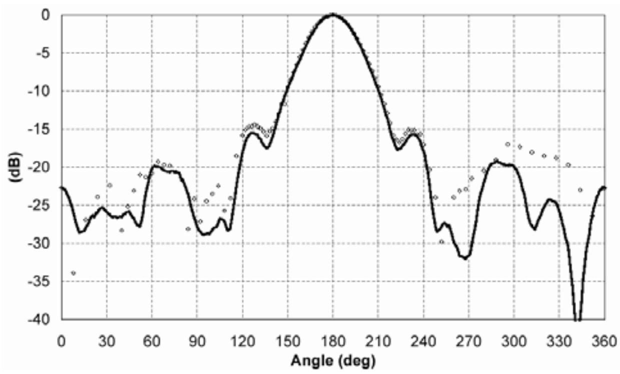

Fig. 9. The radiation patterns of the antenna DRH20 at 8 GHz.

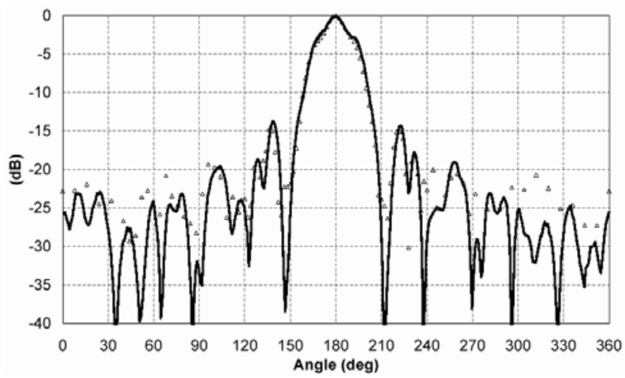

Fig. 10. The radiation patterns of the antenna DRH20 at 18 GHz.

4.2 The Mirror Method of Gain Measurement with Gating in the Time Domain

The presented method of gain measurement with gating in the time domain is based upon a principle that is identical to the previous method. A double-ridged waveguide horn DRH18E [6] was placed at a distance of 2.56 m from the plane reflector with the dimension 2 x 2 m. The gating interval was chosen from 17.6 to 19.6 ns, but due to experience, the widest possible interval is recommended. The horn was directed to the center of the plane reflector, perpendicular to the reflector surface. The gain of the antenna at a distance *R* from the ideal plane reflector is given by the equation [4]:

$$G = 0.5\left[20\log\frac{4\pi \cdot 2R}{\lambda} + (P_R - P_T)\right] \tag{3}$$

with *G* being the gain of the AUT, *R* the antenna to plane reflector distance, λ the wavelength, P_R the gated power level at the output of the AUT and P_T is the power level at the input of the AUT. The term $(P_R - P_T)$ is equal to the gated return loss measurement.

The results of the comparison of the double-ridged waveguide horn gain measurements using a two-antenna method for the antennas' distance of 4.58 m and the mirror method with gating in the time domain for the above mentioned arrangement are depicted in Fig. 11.

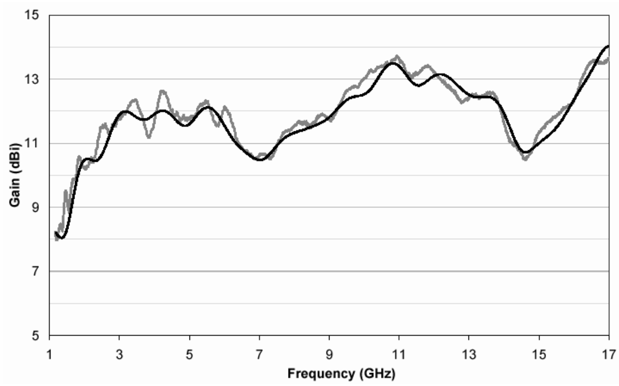

Fig. 11. Gain comparison of double-ridged waveguide horn DRH18E using the two-antenna method (gray line) and the mirror method with gating in the time domain (black line).

The first results show a relatively good agreement with the two-antenna method. The main advantages of the mirror methods of the gain and the radiation patterns measurement with gating in the time domain are their simplicity (single-antenna methods), the more favorable space requirement, the ability to filter out undesired reflected signals (i.e. the measurements do not require an anechoic chamber). The radiation patterns measurement can be realized in a full antenna frequency band in a single antenna turn. The disadvantages of these methods are the necessity to use a sufficiently large flat reflector and additional equipment for the time domain measurement, the limited dynamic range of the obtained radiation patterns and the fact that the presented methods are not suitable to measure circularly-polarized (a reflection changes the sense of circular polarization) and narrow-band antennas (the width of frequency band is proportional to the range resolution in the time domain).

5. Conclusion

The paper describes practical experiences with antenna measurements realized by sweep mode of a vector network analyzer with data processing in a time domain. The new methods of the gain and the antenna radiation patterns measurement which use the mirror method with gating in the time domain were also presented. The results show a good agreement for low dynamic ranges of antenna radiation patterns and also a relatively good agreement with a two-antenna method for gain measurement. The mirror methods with gating in the time domain seem to be the promising methods for measurements of gain and the radiation patterns of ultra-wideband linearly polarized antennas.

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